5-2009

Towards an Integrated Global Agricultural Greenhouse Gas Model: Greenhouse Gases from Agriculture Simulation Model (GreenAgSiM)

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Keywords

agriculture, greenhouse gas emissions, land-use change, methane, nitrous oxide, soil carbon

Disciplines

Agricultural and Resource Economics | Agricultural Economics | Econometrics | Environmental Indicators and Impact Assessment

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Working Paper 09-WP 490
May 2009

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Abstract

The Greenhouse Gases from Agriculture Simulation Model (GreenAgSiM) presented in this paper aims to quantify emissions from agricultural activity on a global scale. The model takes emissions into account that are directly attributable to agricultural production, such as enteric fermentation (methane), manure management (methane and nitrous oxide), and agricultural soil management (nitrous oxide). Furthermore, carbon stock differences from land-use change (carbon dioxide) induced by agriculture are included in the model. The model will provide policy makers with information about the greenhouse gas implications of policy changes.

Keywords: agriculture, greenhouse gas emissions, land-use change, methane, nitrous oxide, soil carbon.

1 Introduction

The Greenhouse Gases from Agriculture Simulation Model (GreenAgSiM) presented in this paper aims to quantify emissions from agricultural activity on a global scale. In our model, agricultural activity not only includes emissions directly attributable to farming such as fertilizer use or livestock emissions but also includes carbon stock differences due to land-use change. The model is based on the Food and Agricultural Policy Research Institute (FAPRI) Agricultural Outlook Model, which is used to project agricultural production in 35 countries and world regions covering 13 crops and two major livestock categories (cattle and swine) over the next 10 years. It is used by policy makers to make informed decisions concerning the impact of changes in agricultural policy. The model is jointly maintained by centers at Iowa State University and the University of Missouri. The need for information in a carbon-constrained world led to the idea to incorporate the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories [1] into the FAPRI modeling framework in order to evaluate the impact of changes in agricultural policy on greenhouse gas emissions.

This paper describes first version of the model and the methods used to evaluate agricultural emissions. GreenAgSiM is composed of three modules: US Agricultural Production, International Agricultural Production, and Land-Use Change. The IPCC provides guidelines on how to implement greenhouse gas inventories to help countries in their efforts to measure emissions and standardize reporting. The guidelines distinguish three levels of complexity for inventories. The lowest level (tier 1), used in this version of the model, employs default values provided by the IPCC for every activity. Tier 2 and tier 3 approaches are based on more complex bio-physical models such as *Century* for soil nitrogen cycles from the National Resource Ecology Laboratory at Colorado State University.

To the best of our knowledge, GreenAgSiM is the first model that includes projections of land-use change and emissions from agricultural production on a global scale. Models such as the Forest and Agricultural Sector Optimization Model (FASOM) or the Global Trade Analysis Project (GTAP) focus only on the US or do not provide the path between two equilibriums. With the FAPRI Agricultural Outlook Model as a building block, it will be possible to analyze the impact of different policy scenarios on greenhouse gas emissions. GreenAgSiM is automated in the sense that several scenarios can be simulated at the same time.

We will not include any results because it is outside the scope of this paper. Scenario runs and results will presented in the near future. We include some possible scenarios for which the model can be applied in the conclusion. Note that, for now, the GreenAgSiM is a static model in the sense that it does not allow for feedback into the rest of the FAPRI Agricultural Outlook Model, e.g., the impact of a cap-and-trade system on agricultural production cost cannot yet be evaluated. These refinements will be included in future versions of the model.

The remainder of the paper is organized as follows. Section 2 will provide a general overview about the GreenAgSiM and its components, country coverage, and commodity coverage. Section 3 describes the agricultural production part of our model, and section 4 outlines the assumptions and methods used to calculate land-use change. The last section concludes the paper and elaborates future improvements and extensions of the model.

2 General Model Description

2.1 Components

The GreenAgSiM estimates emissions according to the categories for national greenhouse gas inventories established by the IPCC. These categories include emission from enteric fermentation and manure management from livestock, agricultural soil management, rice cultivation, and land-use change. The present GreenAgSiM consist of three components, which can be run independently but use the same input data from the FAPRI Agricultural Outlook Model. The three modules of the GreenAgSiM are as follows:

- **International Agricultural Production:** The module includes enteric fermentation, manure management, rice cultivation, and agricultural soil management. It covers all countries but the United States. Furthermore, it comprises only methane (CH_4) and nitrous oxide (N_2O) emissions.
- **US Agricultural Production:** Due to a higher level of data availability for the United States, we separated this module from the international counterpart. In particular, the use of fertilizer in different states is taken into account in this module. Other than that, the same emission sources as in the International Agricultural Production module are used.

- **Land-Use Change:** Emissions induced by land-use change occur if forest and grassland are converted into cropland. Direct land-use change refers to the case in which new cropland devoted to biofuel replaces forest and grassland. Existing cropland which was originally used for food and feed production and is now diverted to biofuel production causes indirect land-use change because part of the lost food and feed production will take place somewhere else. Large amounts of CO_2 are released in the case of deforestation in tropical regions. With the data derived from FAPRI, we try to model and estimate the emissions from direct and indirect land-use change. For the US, we assume that no deforestation takes place if cropland is expanded, i.e., we assume that new cropland comes from set-aside land, such as land in the Conservation Reserve Program (CRP) and grassland. In addition, the model is able to capture carbon sequestration if cropland comes out of production and regrows to natural vegetation.

Note that in section 3, we describe the international and the US parts of agricultural production as if they were one module. The only difference between the two parts is that we have emission factors for the US on a state level whereas for other countries, the data is on an aggregate level. The US Environmental Protection Agency (EPA) publishes a greenhouse gas inventory [2] every year whose methods and data are followed closely in our analysis for the United States. Note that emissions from fuel burning (i.e., agricultural machinery) are not yet considered because these fall into the category of *Energy* of the IPCC. We are aware that in order to calculate emissions from agriculture accurately, farm machinery should be included. This will be done in the future.

2.2 Coverage

The GreenAgSiM as well as the FAPRI Agricultural Outlook Model are global in scale. Major agricultural producers such as the US, EU, Brazil, China, and India are explicitly represented in both models. In order to provide a closure of the models, minor countries are grouped together per continent. Table 1 lists all the countries and groups of countries included in the model. Figure 1 provides a map with the same information. Note that certain countries such as the US, Russian Federation, and China are subdivided into their states. Because of the expanse of these countries, the subdivision is necessary to get accurate predictions about land-use change. Some countries are modeled on the national level, e.g., Algeria, whereas smaller countries are modeled at the continental level. Tables 2 and 3 list all countries, group of countries, crops, and livestock covered in the model.

2.3 Representation of Land

First, a note on the terminology used in the rest of the paper: *region* refers to a group of countries whereas a *state* is a sub-national administrative unit within a country, such as the 50 states in the US.

As previously mentioned, the GreenAgSiM is a global model with the same spatial coverage as the FAPRI Agricultural Outlook Model. However, a few modifications had to be made in order for our model to be more consistent with the FAPRI Model. As opposed to the FAPRI Agricultural Outlook, a region in the GreenAgSiM always consists of the same countries and does not change from one crop or livestock category to the other. Second, the FAPRI Model has a region called *Rest of the World*. This region does not exist in the GreenAgSiM but is grouped into regions such as *Other Asia*, *Other Africa*, and *Other Latin America*. The agricultural output from *Rest of the World* in the FAPRI Agricultural Outlook Model is allocated proportionally into our model. Most of the time, these values are very small and do not affect the accuracy of our predictions.

To represent countries and states, we rely as much as possible on the second level administrative boundary (SALB) codes developed by the United Nations for the coding of countries and states. Every area in figure 1 is assigned a six (eight) character code in which the first three (five) characters specify the country (group of countries) and the last three digits specify the state (country), e.g., ARG001 refers to the state of Buenos Aires in Argentina. We assigned pseudo-codes for the European Union (EUU) and continents, e.g., OTHAF for *Other Africa*. A complete list of countries and regions can be found in table 1.

2.4 Greenhouse Gases

Before we start describing the actual model, it is important to define what greenhouse gases are and how they are measured. There are two main greenhouse gases emitted by agricultural production that are included in national inventory reports submitted to the IPCC: methane (CH_4) and nitrous oxide (N_2O). Note that biomass and soils store carbon. The gas that is contributed by land-use change is carbon dioxide. In order to make methane, nitrous oxide, and carbon comparable, the notion of global warming potential (GWP) is used. The GWP is 21 for methane and 310 for nitrous oxide, i.e., the release of 1 kg of methane (nitrous oxide) is equivalent to releasing 21 kg (310 kg) of CO_2 into the atmosphere. Note that in order to move from carbon (C) to carbon dioxide (CO_2), we have to multiply the carbon content by 3.67. All output of the model is expressed in million tons of CO_2-equivalents. Furthermore, crop area and weights are measured in metric units, i.e., hectares and metric tons.

2.5 Technical Aspects of the GreenAgSiM

The complete model is based on three Microsoft Access databases. Two input tables concerning the crop area harvested and the number of animals are linked with tables containing information about emissions factors, ecological zones, nitrogen application rates, etc. As an example, the entity-relationship model for the International Agricultural Production part is represented in figure 2. The boxes represent tables which contain all the information used to calculate emissions. The linkages between the boxes determine the relationship between the tables and insure data integrity. With the entity-relationship model in place, we can then use SQL (Structured Query Language) queries to retrieve data from the relational database and calculate emissions from enteric fermentation, livestock management, land-use change, etc. This also makes the model fully automated in its calculations.

3 Agricultural Production

3.1 Enteric Fermentation

Enteric fermentation takes place in the digestive system of ruminant animals. In order to estimate CH_4 emissions from enteric fermentation, default values from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [1] are used. The IPCC values for cattle distinguish only between dairy cattle and other cattle. So in our model, we assume *beef cow* to be in the *other cattle* category. Methane emissions from swine are very small. Here the values are 1.5 kg/head/year and 1 kg/head/year for developed and developing countries, respectively. The data necessary are the number of head in the country of interest and the emission factors (Table 4). Simple multiplication between the emission factors, the number of animals, and the greenhouse warming potential of methane leads to total emissions in this category.

3.2 Manure Management

Methane emissions from manure management depend on the temperature the animal is exposed to and the continent. Data from the Food and Agriculture Organization (FAO) were used to determine the livestock distribution within a country or group of countries. For every state (first administrative level) within a country, a coefficient was obtained, which remains unchanged over time. Next, data from weather stations were obtained to match the state/country with its average yearly temperature. This temperature also remains constant over time. An extension of the model would allow this temperature to vary over time and hence measure the impact of climate change on the emissions from livestock. Having the temperature and the location, default emission factors were used to calculate total emissions. Because of the large number of emission factors, we do not present them all here but refer the reader to table 10.14 in the 2006 IPCC Guidelines [1].

Nitrous oxide emissions depend on the use of manure management systems (e.g., daily spread, digester, pasture/range/paddock, etc.). The IPCC provides an estimate of the usage of these systems for different world regions. This method was applied other than the US. For the US, the EPA inventory report provides detailed system usage for every state. Table 5 summarizes the nitrogen excretion rate per animal and per country/region. The table is coupled with manure management system usage by countries and the nitrogen loss by manure management system. Applying standard emission factors results in the nitrous oxide emissions from manure management. Note that we have to take into account the fact that most manure is used as organic fertilizer. So the loss of nitrogen due to the manure management has to be taken into consideration for emissions from agricultural soil management.

3.3 Agricultural Soil Management

By far, the largest category of emissions in agricultural production is soil management. In the preliminary run of the model, we distinguish between emissions from three sources: (1) synthetic fertilizer, (2) organic fertilizer (manure), and (3) other N inputs. For now, other N inputs includes mineralization from soil organic matter.

The Forest and Agricultural Sector Optimization Model (FASOM) provides us with data about the application rate of nitrogen fertilizer in the US for different crops and regions. Global fertilizer application rates for the crops in question are obtained from the FAO [3]. These values are summarized in table 6. The FAO does not provide fertilizer application rates for all countries but rather for a selection of countries. Where data were not available, fertilizer rates from the closest matching country were used.

The chemical composition of manure applied to cropland depends on the nitrogen excretion rate of the animal located in different world regions, as reported by the

IPCC. We have to take into account that some of the nitrogen from animals is lost because of the manure management system. The rest is applied as organic fertilizer to cropland.

4 Land-Use Change

4.1 General Overview

Land-use and land-use change are seen to be the biggest problems in assessing greenhouse gas emissions from agriculture. For example, research by Searchinger et al. [6] and Fargione et al. [4] suggests that an increase in US biofuel production induces direct and indirect land-use change in the US and elsewhere. The expansion of cropland into grassland and forests causes the release of carbon stored in soil and biomass and hence reduces the carbon benefit of biofuels significantly. It is very difficult to measure land-use change explicitly because the only way to measure it is through remote sensing, i.e., satellite imagery. Consistent time-series data from remote sensing are not available on a global scale for now. Thus, we rely on GIS[1] data and use a simple method to model land-use change in the GreenAgSiM.

In our model, we distinguish two types of sources/sinks of carbon from land-use and land-use change:

- **Biomass:** The biomass in forests is determined by the ecological zone, the type of native vegetation, and the continent. The IPCC guidelines give the average above-ground biomass (in tonnes of dry mass per hectare) and the shoot to root ratio. A default factor of 0.47 tonnes of carbon per tonne of dry matter is used to calculate the biomass in CO_2-equivalent. This category also includes forgone carbon sequestration due to land-use conversion. To determine the forgone carbon uptake, knowledge about the forest's age distribution is necessary. In most cases this information is not available and hence we assume a 50/50 distribution of trees younger and older than 20 years. It turns out that the age distribution has a rather small impact on the forgone carbon uptake because younger trees sequester at a higher rate per year but for a shorter period (until they are over 20 years) and older trees sequester at a lower rate for a longer period.

[1] We are thankful to the Food and Agriculture Organization of United Nations which provided us with the Global Administrative Unit Layer dataset.

- **Soil:** If land is converted to cropland, carbon stored in soils (soil organic carbon) is released into the atmosphere. The change in the amount of soil organic carbon (SOC) depends on factors such as climate region, native soil type, management system after conversion, and input use. A global soil map (FAO Soil Map) was obtained, which subdivides soil into three large categories (20 t/ha, 40 t/ha, and 80 t/ha). As mentioned before, the conversion is assumed to be from grassland, savanna, shrubland, and forests to cropland. We assumed that cropland is managed with medium input and full tillage. The top 30 cm of carbon is supposed to be lost after initial cultivation and once taken out of cultivation reaches the new equilibrium (initial stage) in 20 years.

In the following sections, we provide a description of the model for biomass and for soil carbon. Section 4.4 in this part provides a calculation example for China.

4.2 Biomass

First, the distribution of agricultural production was determined using the FAO Global Spatial Database of Agricultural Land-use (Agro-Maps) on a first level administrative unit scale. For regions, data from the USDA Production, Supply & Distribution (PS&D) database was used to determine production coefficients. Second, a GIS map of native vegetation [5] was put together with a map of ecosystems (global ecological zones) to establish the type of native vegetation where an agricultural activity takes place. A map of native vegetation was used to evaluate if the undisturbed land in a particular region is forest, shrubland, grassland, or savanna. Together with the map of ecosystems, this helps us to map the default values of the IPCC to match with the region of interest.

To determine the effect of agricultural expansion, we assume that regions that have a high proportion of agricultural activity are more likely to see a cropland expansion. Suppose a country has two states, A and B. If the allocation of wheat area in that country is 80% in state A and 20% in state B, then an increase of 100 hectares would be allocated as 80 ha in state A and 20 ha in state B. This assumption poses the problem that an administrative unit/state might already be at 100% capacity and that an expansion is not possible. A remedy consists of determining the arable share of every state and then to base the expansion on the capacity. This, however is not feasible for most countries because of data limitations.

4.3 Soil

A map of soil organic carbon from the FAO was used to determine the stock of carbon in the first 30 cm of soil (see figure 3). The IPCC provides default factors by which the reference carbon stock (C) has to be multiplied depending on the climate region, land-use (S), and management type (M). The coefficients used in the GreenAgSiM can be found in tables 7 and 8.

Next, we need to know the tillage system applied for every country. Because of limited data availability, we assume for now that full tillage is applied in every country/state. This assumption will be relaxed if more data becomes available.

4.4 Example

We will now use the example of wheat production in China to explain our method of calculating land-use change and soil carbon emissions. Figure 4 shows the 30 administrative regions in China. Figure 5 features the area of wheat production in China in percentage of total production. To illustrate the calculation method, we will use the Chinese state of Shanxi (CHN027). Table 9 summarize the ecological profile of the state. The ecological profile was determined by overlaying the maps in figures 6 and 7. Of the Chinese wheat area, 3.16% is located in Shanxi. So in case of a 10,000 ha increase in wheat area, 316 acres will be allocated in that state. The biomass carbon loss will then be a weighted average of the four ecosystems that prevail in Shanxi.

With regard to the loss of soil carbon, we assume that the average soil carbon of the native ecosystem (C_0) is

$$C_0 = 0.17 \cdot 20 + 0.83 \cdot 40 = 36.6 \frac{t}{ha}$$

Given the climate region of the state, we find that after conversion, the weighted average carbon stock is

$$C_1 = 26.36 \frac{t}{ha}$$

which results in a carbon loss of 10.24 tons per ha. If the area decreased by 10,000 ha, we assume that the soil would sequester carbon over 20 years back to the original carbon stock of 36.6 tons, i.e., 0.5120 t/ha/year.

5 Conclusion

Our model is the first known version of a globally integrated agricultural greenhouse gas model that can be used to answer a wide array of questions concerning greenhouse gas emissions and agriculture. It is conceived as a tool for policy makers to make informed decisions in a carbon-constrained world. GreenAgSiM includes all major greenhouse gas emission sources from agriculture, such as methane from livestock, nitrous oxide from crops, and carbon dioxide from land-use change. It will be continuously refined to reflect the most current knowledge of greenhouse gas emission from land-use and agricultural production.

Possible applications and uses of the model are to assess

- the effects of an increase in grain yield or other events that increase land productivity on greenhouse gases;
- the effects of policy changes involving anhydrous ammonia use on greenhouse gas emissions;
- the effects of policy changes related to conservation tillage on greenhouse gas emissions;
- the impact of the EPA proposed "sin" tax on livestock for methane emissions;
- offset options that trade off the positive impact of national yield increases or beneficial policy changes against other policies that result in an increase in agricultural greenhouse gas emissions.

In future versions of the model, we will include the fact that crops that sequester carbon and are exported can be considered to be a carbon credit for the exporting country and a carbon burden for the importing country.

References

[1] Simon Eggleston, Leandro Buendia, Kyoko Miwa, Todd Ngara, and Kiyoto Tanabe. 2006 IPCC national guidelines for greenhouse gas inventories. Technical report, Intergovermental Panel on Climate Change, 2006.

[2] EPA. Inventory of U.S. greenhouse gas emissions and sinks: 1990-2005. Technical report, Environmental Protection Agency, 2007.

[3] FAO. Fertilizer use by crop. Technical report, Food and Agricultural Organization, 2006.

[4] Joseph Fargione, Jason Hill, David Tilman, Stephen Polasky, and Peter Hawthorne. Land clearing and the biofuel carbon debt. *Science*, 319:1235, 2008.

[5] David M. Olson, Eric Dinerstein, Eric D. Wikramanayake, Neil D. Burgess, George V. N. Powell, Emma C. Underwood, Jennifer A. D'amico, Illanga Itoua, Holly E. Strand, John C. Morrison, Colby J. Loucks, Thomas F. Allnutt, Taylor H. Ricketts, Yumiko Kura, John F. Lamoreux, Wesley W. Wettengel, Prashant Hedao, and Kenneth R. Kassem. Terrestrial ecoregions of the world: A new map of life on earth. *BioScience*, 51(11):933–938, 2001.

[6] Timothy Searchinger, Ralph Heimlich, R. A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science*, 319(5867):1238–1240, 2008.

Table 1: Country codes and continents

Code	Country	Continent
DZA	Algeria	Africa
ARG	Argentina	South America
AUS	Australia	Oceania
BRA	Brazil	South America
CAN	Canada	North America
CHN	China	Asia
EGY	Egypt	Africa
EUU	European Union	Europe
IND	India	Asia
IDN	Indonesia	Asia (Insular)
IRN	Iran (Islamic Republic of)	Asia
ISR	Israel	Asia
JPN	Japan	Asia
MYS	Malaysia	Asia
MEX	Mexico	North America
MOR	Morocco	Africa
NGA	Nigeria	Africa
OTHAF	Other Africa	Africa
OTHAS	Other Asia	Asia
OTHCI	Other CIS	Asia
OTHEE	Other Eastern Europe	Europe
OTHLA	Other Latin America	South America
OTHME	Other Middle East	Asia
PAK	Pakistan	Asia
PHL	Philippines	Asia (Insular)
KOR	Republic of Korea	Asia
RSF	Russian Federation	Asia
SAU	Saudi Arabia	Asia
ZAF	South Africa	Africa
TAW	Taiwan	Asia
THA	Thailand	Asia
TUR	Turkey	Asia
UKR	Ukraine	Asia
USA	United States	North America
VNM	Viet Nam	Asia

Table 2: Country and crop coverage

Country	Sub-national	Wheat	Rice	Corn	Barley	Sorghum	Soybean	Rapeseed	Sunflower	Palm Oil	Peanut	Cotton	Sugar Beet	Sugar Cane
Algeria		•		•	•									
Argentina	•	•	•	•	•	•	•		•		•	•		•
Australia	•	•	•	•	•	•		•				•		•
Brazil	•	•	•	•	•		•					•		•
Canada	•	•	•	•	•		•	•			•	•	•	
China	•	•	•	•	•		•	•	•	•	•	•	•	•
Egypt		•	•	•									•	•
EU	•	•	•	•	•		•	•	•	•	•	•	•	•
India	•	•	•	•		•	•	•		•	•	•		•
Indonesia	•		•	•						•		•		•
Iran		•	•										•	•
Israel				•	•	•								
Japan		•	•	•	•	•	•	•				•	•	•
Malaysia	•		•	•						•				•
Mexico	•	•	•	•	•	•	•				•	•		•
Morocco		•											•	•
Nigeria			•			•								
Other Africa	•			•	•							•		
Other Asia	•	•		•	•							•		
Other CIS	•	•		•	•		•	•	•			•		
Other Eastern Europe	•	•		•	•									
Other Latin America	•	•		•	•		•					•		•
Other Middle East	•			•	•							•		
Pakistan		•	•	•	•	•						•	•	•
Philippines	•		•	•										•
Republic of Korea		•	•	•			•					•		
Russian Federation	•	•		•	•							•	•	
Saudi Arabia			•		•									
South Africa			•	•	•	•						•		•
Taiwan		•	•	•	•		•					•		•
Thailand			•	•										•
Turkey			•									•	•	
Ukraine		•		•	•								•	
United States	•	•		•	•	•	•	•	•			•	•	•
Viet Nam			•	•										

Table 3: Country and livestock coverage

Country	Sub-national	Beef Cow	Dairy Cow	Other Cattle	Breeding Swine	Market Swine
Algeria		•	•	•		
Argentina	•	•	•	•	•	•
Australia	•	•	•	•	•	
Brazil	•	•	•	•		•
Canada	•	•	•	•		•
China	•	•	•	•		•
Egypt		•	•			
EU	•	•	•	•		•
India	•	•	•		•	•
Indonesia	•		•			
Iran		•				
Israel			•	•	•	
Japan		•	•	•	•	•
Malaysia	•		•			
Mexico	•	•	•	•	•	
Morocco		•				
Nigeria					•	
Other Africa	•					
Other Asia	•					
Other CIS	•					
Other Eastern Europe	•					
Other Latin America	•					
Other Middle East	•					
Pakistan		•	•	•	•	
Philippines	•		•			
Republic of Korea		•	•			•
Russian Federation	•	•	•	•		
Saudi Arabia				•		
South Africa			•	•	•	
Taiwan			•	•		•
Thailand			•			
Turkey						
Ukraine		•	•	•		
United States	•	•	•	•	•	•
Viet Nam			•			

Table 4: Methane emissions from enteric fermentation in kg CH_4/head/year

	Beef Cow	Dairy Cow	Other Cattle	Breeding Swine	Market Swine
Africa	31	40	31	1	1
Asia	47	61	47	1	1
Eastern Europe	58	89	58	1.5	1.5
Indian Subcontinent	27	51	27	1	1
Latin America	56	63	56	1	1
Middle East	31	40	31	1	1
North America	53	121	53	1.5	1.5
Oceania	60	81	60	1.5	1.5
Western Europe	57	109	57	1.5	1.5

Table 5: Nitrogen excretion in kg N/head/day

Country	Beef Cow	Dairy Cow	Other Cattle	Breeding Swine	Market Swine
ARG	40.1	70.1	40.1	5.6	16.0
AUS	60.2	80.3	60.2	30.2	8.7
BRA	40.1	70.1	40.1	5.6	16.0
CAN	44.0	97.0	44.0	17.3	7.1
CHN	39.6	60.0	39.6	2.5	4.3
DZA	39.8	60.2	39.8	5.6	16.0
EGY	39.8	60.2	39.8	5.6	16.0
EUU	50.6	105.1	50.6	30.4	9.3
IDN	39.6	60.0	39.6	2.5	4.3
IND	13.7	47.2	13.7	2.5	4.3
IRN	49.9	70.3	49.9	5.6	16.0
ISR	49.9	70.3	49.9	5.6	16.0
JPN	39.6	60.0	39.6	2.5	4.3
KOR	39.6	60.0	39.6	2.5	4.3
MEX	44.0	97.0	44.0	17.3	7.1
MOR	39.8	60.2	39.8	5.6	16.0
MYS	39.6	60.0	39.6	2.5	4.3
NGA	39.8	60.2	39.8	5.6	16.0
OTHAF	39.8	60.2	39.8	5.6	16.0
OTHAS	39.6	60.0	39.6	2.5	4.3
OTHCI	50.0	70.3	50.0	30.2	10.0
OTHEE	50.0	70.3	50.0	30.2	10.0
OTHLA	40.1	70.1	40.1	5.6	16.0
OTHME	49.9	70.3	49.9	5.6	16.0
PAK	39.6	60.0	39.6	2.5	4.3
PHL	39.6	60.0	39.6	2.5	4.3
RSF	39.6	60.0	39.6	2.5	4.3
SAU	49.9	70.3	49.9	5.6	16.0
TAW	39.6	60.0	39.6	2.5	4.3
THA	39.6	60.0	39.6	2.5	4.3
TUR	39.6	60.0	39.6	2.5	4.3
UKR	50.0	70.3	50.0	30.2	10.0
USA	44.0	97.0	44.0	17.3	7.1
VNM	39.6	60.0	39.6	2.5	4.3
ZAF	39.8	60.2	39.8	5.6	16.0

Table 6: Nitrogen Application Rate (kg N/ha)

Country	Wheat	Rice	Corn	Barley	Sorghum	Soybean	Rapeseed	Sunflower	Palm Oil	Peanut	Cotton	Sugar Beet	Sugar Cane
Algeria	33		55	6									
Argentina	40	36	28	73	36	2		10		35	5		46
Australia	20	131	111	10	60		41				134		49
Brazil	12	27	40	43		8					83		55
Canada	65	150	193	36		6	41			35	100	100	
China	184	181	178	173		48	99	10	100	35	115	30	126
Egypt	169	119	233									30	227
EU	110	66	105	91		58	58	58	58	58	58	58	58
India	100	82	42		29	35	69		89	35	90		125
Indonesia		105	5						89		115		90
Iran	58	105										30	227
Israel			111	182	28								
Japan	15	19	115	6	28	43	69				115	30	126
Malaysia		131	111						128				87
Mexico	130	150	80	65	80	40				35	120		100
Morocco	27											30	227
Nigeria		3			1								
Other Africa			5	24							12		
Other Asia	15		115	6							23		
Other CIS	15		17	20		40	69	10			100		
Other Eastern Europe	15		17	20									
Other Latin America	94		58	123		8					62		36
Other Middle East			111	76							155		
Pakistan	133	136	111	76	28						155	30	99
Philippines		49	44										9
Republic of Korea	15	147	115			12					23		
Russian Federation	7		56	16							100	30	
Saudi Arabia		136		76									
South Africa		50	55	50	50						36		92
Taiwan	1	42	4	1		1					1		7
Thailand		31	61										16
Turkey		119									58	84	
Ukraine	15		17	20								22	
United States	•		•	•	•	•	•	•			•	•	•
Viet Nam		101	127										

Table 7: Land-use factor (S) dependent on system

Land-use	Cool Temperate Dry	Cool Temperate Moist	Boreal Dry	Boreal Moist	Tropical Dry	Tropical Moist	Warm Temperate Dry	Warm Temperate Moist
Forest	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grassland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Long-term cultivated	0.82	0.71			0.69	0.58	0.82	0.71
Set aside (<20 yrs)	0.93	0.82			0.93	0.82	0.93	0.82

Table 8: Tillage

	Cool Temperate Dry	Cool Temperate Moist	Tropical Dry	Tropical Moist	Warm Temperate Dry	Warm Temperate Moist
Full Tillage	1.00	1.00	1.00	1.00	1.00	1.00
No Tillage	1.10	1.16	1.17	1.23	1.10	1.16
Reduced Tillage	1.03	1.09	1.10	1.16	1.03	1.09

Table 9: Wheat Production and Ecological Profile in the Chinese Province of Shinxa

Wheat Production Shinxa			
Wheat Production as % of Total Production		3.16%	
Biomass Carbon Content in t/ha	Land Type	Share	
Temperate mountain system	Grassland	19.00%	19.58
Temperate steppe	Grassland	0.04%	9.36
Temperate steppe	Forest	0.15%	302.72
Temperate mountain system	Forest	80.81%	372.58
Soil Carbon Content in t/ha		Share	Content
Soil Carbon		17%	20
Soil Carbon		83%	40

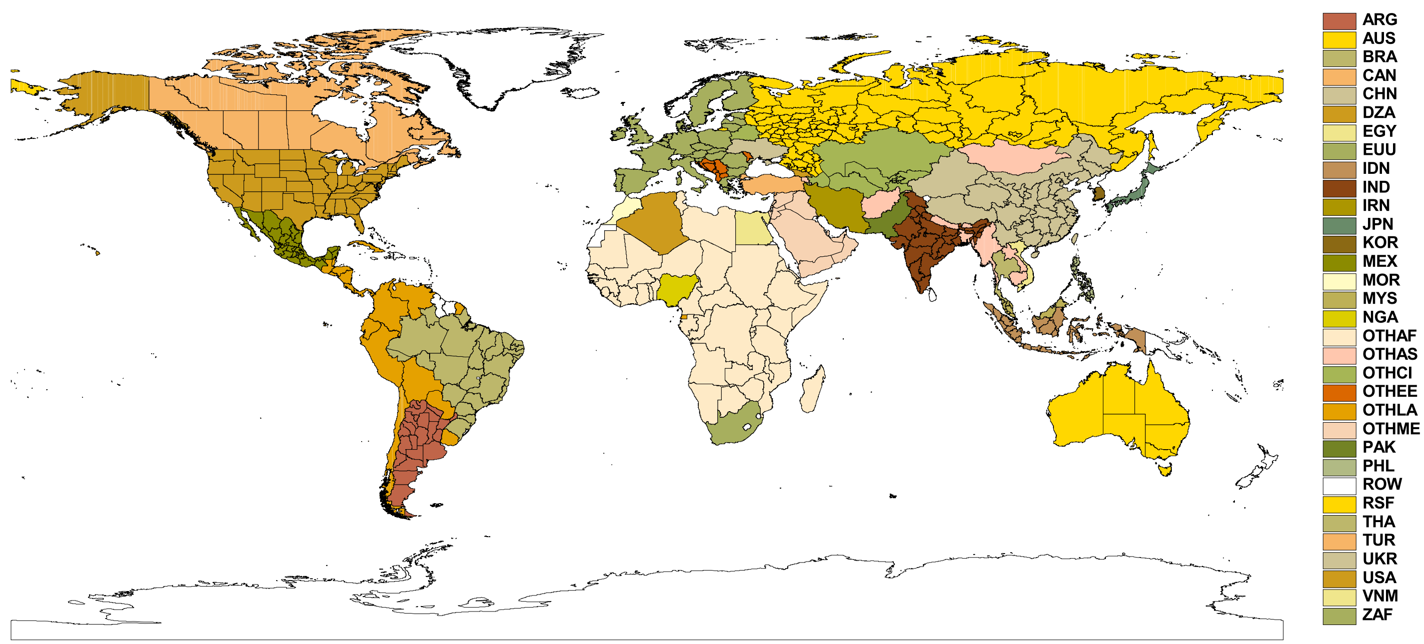

Figure 1: Country and region coverage of the GreenAgSiM

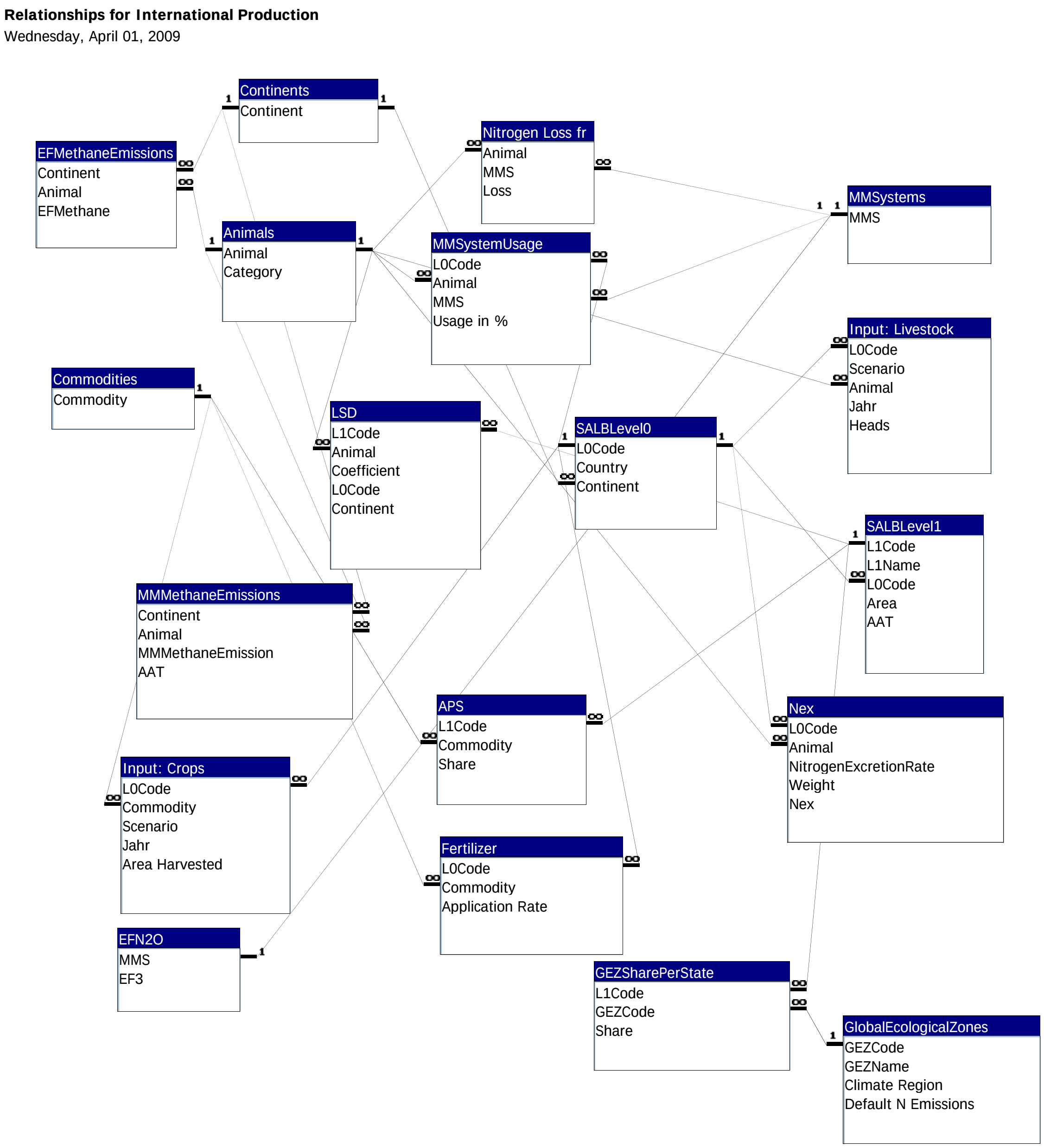

Figure 2: Entity-relationship model for the International Agricultural Production module

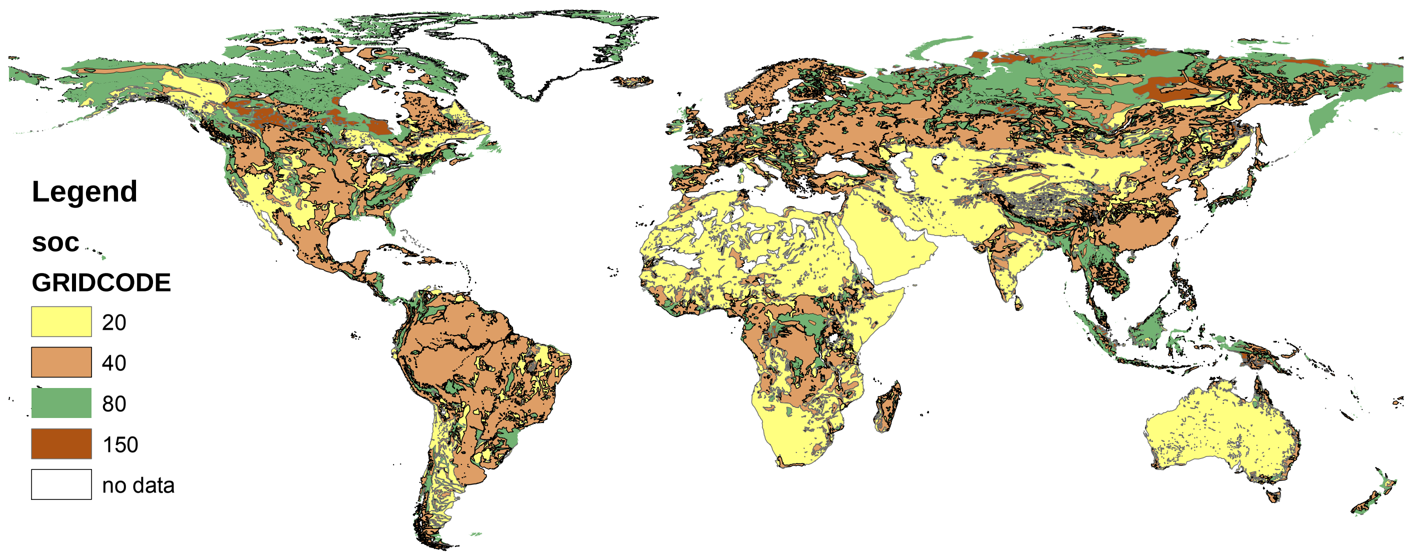

Figure 3: Soil Organic Carbon in the first 30cm in tons/hectare

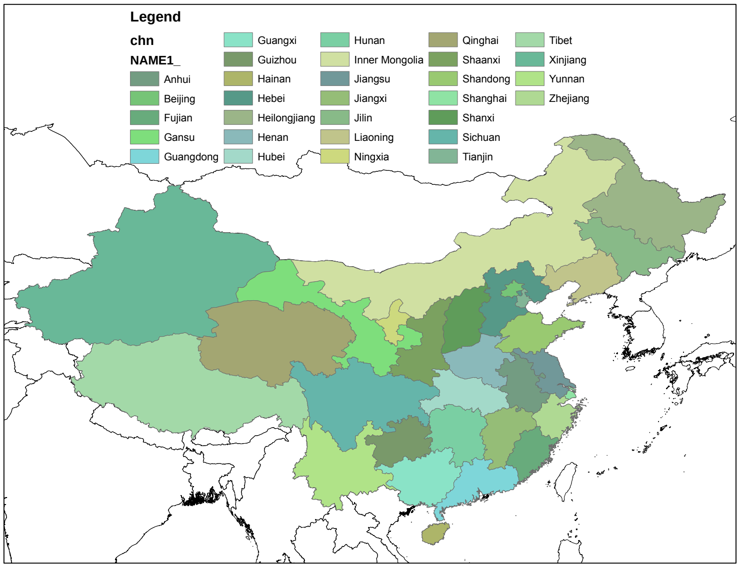

Figure 4: Administrative regions in China

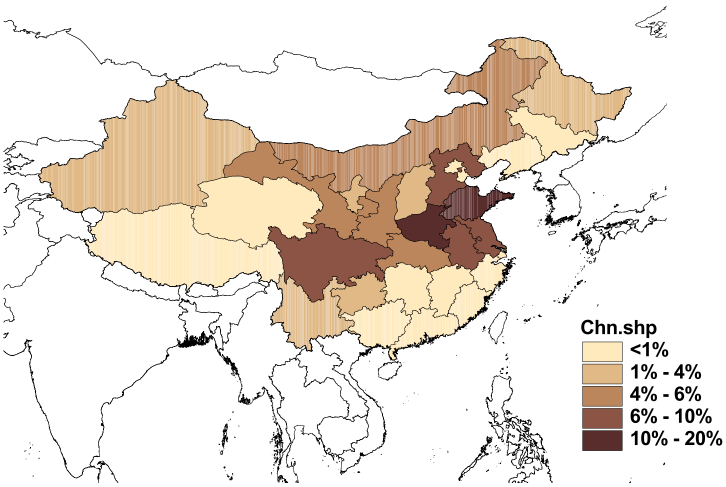

Figure 5: Wheat production in China

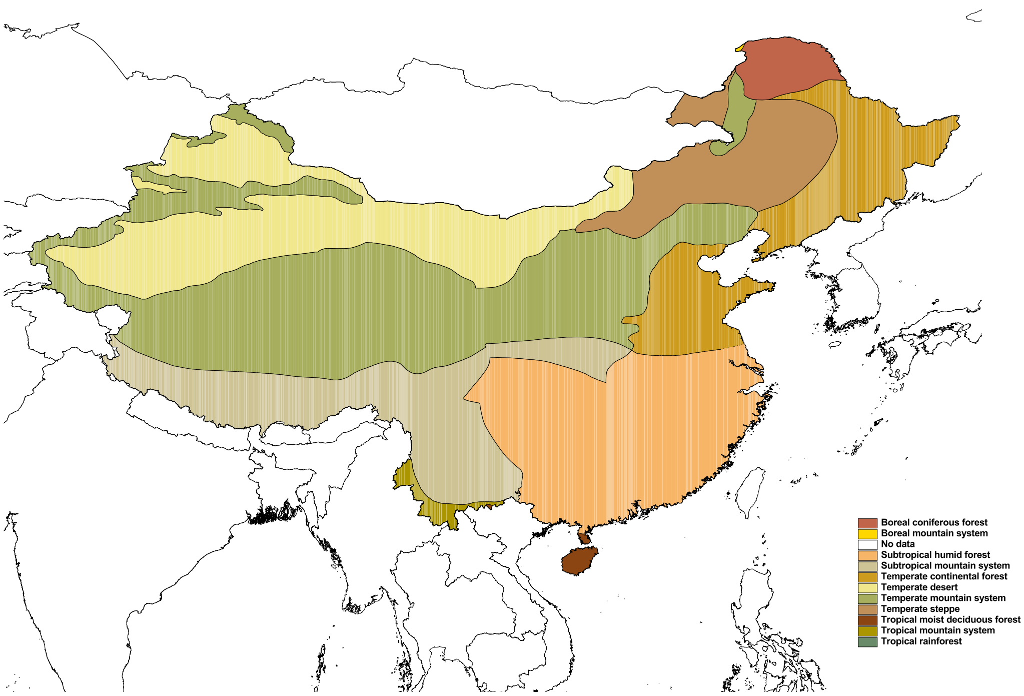

Figure 6: Global Ecological Zones in China

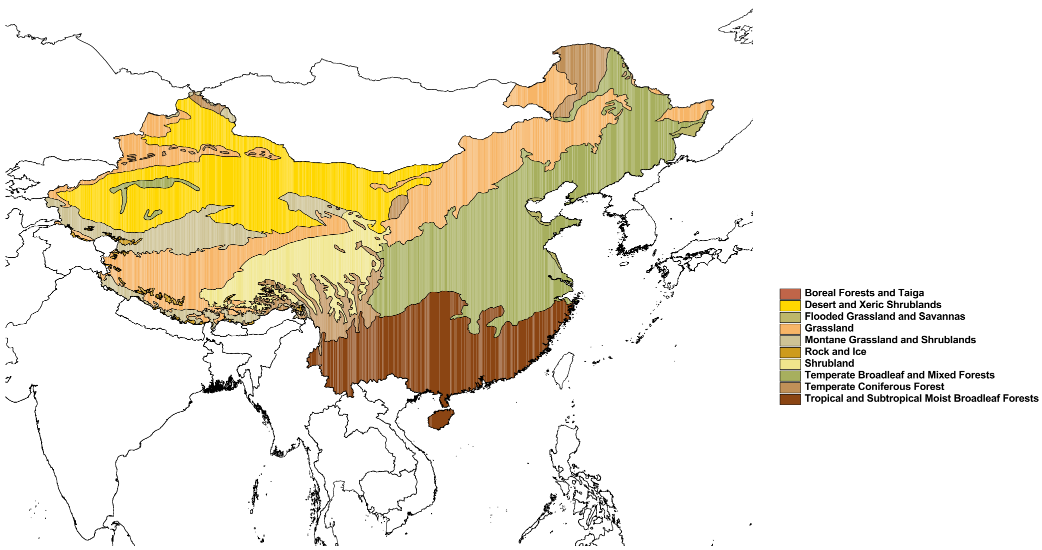

Figure 7: Biomes in China